Nondestructive testing for in-place assessment of wood members

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Abstract

Nondestructive evaluation (NDE) of materials, the science of identifying the physical and mechanical properties of materials without altering their end-use capabilities, is valuable in defining relationships between properties and performance of materials. NDE techniques using these relationships have current industrial applications. They are used for machine stress rating of lumber, and ultrasonic veneer grading for laminated veneer lumber manufacture. Studies using NDE have been used for in-place detection of decay in wood structures such as bridges, grandstands, piers, and laminated arches. We have prepared a comprehensive report that reviews nondestructive testing of wood research and application techniques. This paper provides a brief synopsis of that report.

Introduction

Nondestructive evaluation (NDE) of materials is, by definition, the science of identifying the physical and mechanical properties of a piece of material without altering its end-use capabilities. Such evaluations rely upon nondestructive testing (NDT) techniques or tools to provide accurate information pertaining to the properties and performance of the material in question.

During the past 30 years, forest products researchers and the forest products industry have developed and used NDT tools for a wide range of applications—from the grading of structural lumber to the in-place evaluation of the mechanical properties of individual members in wood structures. The USDA Forest Products Laboratory (FPL) recently published a report that reviews NDT techniques used with wood products (28). This paper provides a brief overview of that report.

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Fundamental concepts and pioneering research efforts

NDT techniques for wood differ greatly from those for homogeneous, isotropic materials such as metals, glass, plastics, and ceramics. In such non-wood materials, whose mechanical properties are known and tightly controlled by manufacturing processes, NDT techniques are used to detect the presence of discontinuities, voids, or inclusions. Because wood is a biological material, these irregularities occur naturally and may occur because of agencies of degradation in the environment. Hence, NDT techniques for wood are used to measure how natural and environmentally induced irregularities interact in a wood member to determine its mechanical properties.

Armed with this concept, early forest products researchers vigorously examined several techniques for grading structural lumber and evaluating the quality of laminated materials (4,10,12,14-16,18,31). Out of these pioneering efforts evolved a hypothesis, founded on fundamental material properties, for establishing relationships between NDT parameters and static mechanical properties of wood products.

The fundamental hypothesis for NDT of wood materials was first presented by Jayne (16). He proposed that the energy storage and dissipation properties of wood materials, which can be measured nondestructively by using a variety of static and dynamic techniques, are controlled by the same mechanisms that determine the mechanical behavior of such materials. As a consequence, useful mathematical relationships between these properties and elastic and strength behavior should be attainable through statistical regression analysis methods.

To elaborate on Jayne's hypothesis, consider how the microscopic structure of clear, straight-grained wood affects mechanical behavior and energy storage and dissipation properties. Clear wood is a composite material composed of many tube-like cells cemented together. At the microscopic level, energy storage properties are controlled by orientation of the cells and their structural composition, factors that contribute to elasticity and strength. Such properties are observed at frequency of oscillation in vibration or speed of sound transmission. Energy dissipation properties, conversely, are controlled by internal friction characteristics, with bonding behavior between constituents contributing significantly. Rate of decay of free vibration or acoustic wave attenuation measurements are frequently used to observe energy dissipation properties.

Early laboratory studies to verify Jayne's hypothesis were conducted with clear wood and lumber products. Jayne (16) successfully demonstrated a relationship between energy storage and dissipation properties, measured using forced transverse vibration techniques, and the static bending properties of small, clear wood specimens. His technique was based on forcing a bending member to produce transverse oscillations.

Pellerin (22) verified the hypothesis using free transverse vibration techniques and dimension lumber. Pellerin's effort differed from that of Jayne in that the specimens were allowed to oscillate in response to an initial deflection. No forcing function was applied. Kaiserlik and Pellerin (17) furthered the hypothesis by using stress wave techniques (longitudinal oscillation) to evaluate the tensile strength of a small sample of clear lumber containing varying degrees of slope of grain.

Current industrial applications

Machine stress rating (MSR) of lumber and ultrasonic veneer grading for laminated veneer lumber manufacture are two current industrial applications of NDT that developed from early research efforts.

Machine stress rating, as currently practiced in North America, couples visual sorting criteria with nondestructive measurements of the stiffness of a piece of lumber to assign it to an established grade (10). Machines measure the modulus of elasticity (MOE) of individual specimens that are passed through endwise. They accomplish this by measuring the bending deflection resulting from a known load or by measuring the load required to accomplish a given amount of deflection. Special features of some machines include sensitivity to low-point elasticity, the ability to detect sections of lumber that may have MOE values much lower than the average of the piece. Design stresses are determined from machine MOE values, using a regression between MOE and strength.

Laminated veneer lumber manufacturing facilities use stress wave NDT techniques to sort incoming veneer into strength classes prior to processing the veneer into finished products. Veneers are assigned to strength categories established through empirical relationships between stress wave velocity and strength, based on the velocity at which an ultrasonically induced stress wave travels through the wood **(32).**

Current research activity

Considerable research activity has recently focused on applying NDT concepts to wood-based composites, decay detection, and in-place evaluation of wood structures. In addition, current research is aimed at enhancing current MSR techniques and developing low-cost MSR systems.

Wood-based composites

Successful verification of Jayne's hypothesis (16) using stress wave techniques on wood-based composites has been shown by Pellerin and Morschauser (25), Ross (26), Ross and Pellerin (27), and Vogt (33). Pellerin and Morschauser (25) showed that stress wave speed, a measure of energy storage properties, could be used to predict the flexural behavior of underlayment-grade particleboard. Ross (26) and Ross and Pellerin (27) revealed that wave attenuation, a measure of energy dissipation properties, was sensitive to bonding characteristics and is a valuable NDT parameter that contributes significantly to predicting the tensile and flexural mechanical behavior of wood-based particle composites. Vogt (33) furthered application of the hypothesis to wood-based fiber composites. In another study, Vogt (34) also found a strong relationship between internal bond and stress wave parameters of particle and fiber composites.

Decay detection

Verification of Jayne's hypothesis with wood subjected to different levels of deterioration by decay fungi, which have a detrimental effect on the mechanical properties of wood and are commonly found in wood structures, has been limited to studies that have employed only energy storage parameters. Wang et al. (35), for example, found that the frequency of oscillation of small, eastern pine, sapwood cantilever bending specimens was significantly affected by the presence of decay. Pellerin et al. (24) showed that stress wave speed could be used successfully to monitor the degradation of small, clear wood specimens exposed to brown-rot fungi. They showed a strong correlation between stress wave speed and the compressive strength parallel to the grain of exposed wood. Rutherford (30) showed similar results. He also revealed that MOE perpendicular to the grain, measured using stress wave techniques, was significantly affected by degradation from brown-rot decay and could be used to detect incipient decay. Chudnoff et al. (6) reported similar results from experiments that utilized an ultrasonic measurement system and several hardwood and softwood species. Patton-Mallory and De-

Groot (21) reported similar results from a fundamental study dealing with the application of acousto-ultrasonic techniques. Their results also showed that energy loss parameters may provide useful additional information pertaining to early strength loss from incipient brown-rot decay.

Acoustic emission techniques have also been investigated for use in decay detection. Utilizing a small sample of clear white fir specimens infected with brown-rot fungi, Beall and Wilcox (2) showed a relationship between selected acoustic emission parameters and radial compressive strength.

In-place evaluation

Several organizations have published results of their efforts using these concepts for in-place evaluation of wood structures. Pellerin (23) summarized his results and those of others (5,12,13,20) on successful use of stress wave methods for in-place decay detection in wood structures. All studies used energy storage parameters from stress wave, time-of-flight-type measurement systems. Structures evaluated successfully included bridges, footbridges, grandstands for spectator activities, piers, laminated arches in school buildings, and the world's largest wood structure, TRESTLE.

Anthony and Bodig (1) reported on the use of sonic spectral analysis techniques they developed and used for the inspection of wood structures. Murphy et al. (19) and Dunlop (8) reported on the use of acoustic and vibration techniques for evaluating wood poles. The technique developed by Murphy et al. (19) involved measuring the vibrational response of a pole after tapping it with a rubber mallet. Dunlop (8) utilized an electronic system, sweeping through a selected range of excitation frequencies, to develop an acoustic signature of a pole. Resonant frequencies and their bandwidths were examined for use as NDT parameters.

MSR techniques and low-cost systems

Research using noncontact scanning technology with conventional MSR systems is yielding encouraging results. This research has been aimed at providing more accurate estimates of the strength of lumber products and promises to significantly enhance the use of lumber in engineered applications (3,7).

Considerable effort is also being devoted to developing tools for low-cost MSR systems (29). This effort couples relatively inexpensive personal computer technologies and transverse vibration NDT techniques by innovative software programming. Tools developed from this effort promise to yield MSR systems at costs considerably lower than the costs of those currently used. This will make MSR lumber grading available to a wider range of wood products manufacturers and users.

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